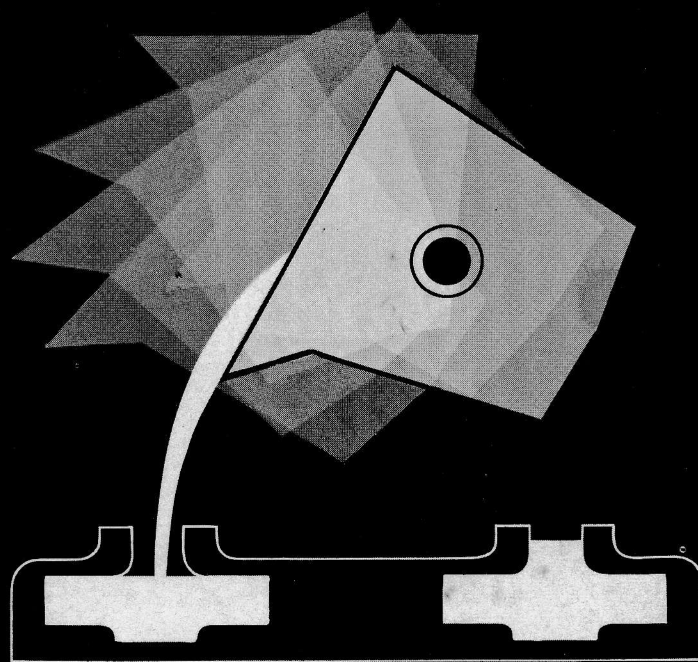
CASTING ALUMINUM



REYNOLDS

METALS CO.

Foreword: The purpose of this booklet is to provide a better understanding of the design and production of aluminum castings. It includes clear and concise information to help the designer select the casting process and the aluminum alloy best suited to meet the requirements of the product.

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CASTING ALUMINUM

Aluminum castings have many important advantages that account for their increasing use in automobile and aircraft industries, in ornamental and architectural fields, in household appliances and many other applications. Industrial machines and portable tools of all types, anything that moves or must be moved, is today following the trend toward aluminum . . . and aluminum castings are playing a vital part in this picture.

The significant features of aluminum lie in the weight savings afforded by its light weight, and its high resistance to corrosion, good electrical and thermal conductivity, favorable mechanical properties, excellent workability and low ultimate cost.

Equally important, aluminum is one of the relatively few materials that can be cast by all three common casting methods . . . sand, permanent mold, and pressure die casting. This versatility has been enhanced by development of special aluminum casting alloys for each casting method, designed to utilize the particular inherent advantages of that method. The term "aluminum" as used here also includes the aluminum alloys.

CASTING METHODS

Sand Casting: The oldest and most familiar method of casting uses molten aluminum poured into either green sand or baked sand molds.

Permanent-Mold Casting employs molds made from cast iron or steel with thick walls which provide sufficient thermal capacity to assure rapid chilling of cast metal. In semi-permanent-mold casting, sand or plaster cores are used in a cast iron or steel mold to produce the more intricate and complex shapes.

Die Casting employs pressure to force the molten metal into the cavities in a steel die.

In addition to these three common processes, others of limited application include centrifugal casting, investment or precision casting, plaster-mold, and shell-mold casting.

Choosing the Process is important as it not only determines many features of the casting design but also affects the choice of alloy.

Volume: Since pattern equipment for sand casting is much less expensive than dies for permanent-mold or pressure die casting, sand casting is indicated where small quantities are wanted. Larger quantities call for permanent-mold or die casting, depending upon the size and complexity of the casting.

Size Limitations affect sand casting the least, with permanent-mold casting next. Die casting finds size restrictions most limited as cost of die-casting machine and dies rises steeply with increased size of the casting.

Dimensional Tolerances: Sand casting can be employed where relatively large dimensional tolerances are allowable. For closer tolerances, use metal dies and permanent mold or pressure die casting.

Surface Finish may be a determining factor in certain instances, because metal dies usually produce a smoother surface than sand molds. Savings in machining or finishing may justify the added cost of the metal molds where otherwise the quantities involved would rule out the permanent-mold or die-casting processes.

Shapes: Exceptionally intricate shapes can be cast in sand molds, using various types of core structures. This is the most versatile process as far as shape of the casting is concerned.

Mechanical Properties obtainable with permanent-mold and die-casting processes are generally higher than with sand casting because the metal molds produce more rapid solidification and hence improve soundness and microstructure.

Quicker Delivery is usually enjoyed when sand casting because making metal dies requires more time. Of course, this applies only to delivery of the initial order. Once the metal dies have been made, an order for most any given quantity can be turned out faster with them than with sand molds because of their inherently faster operation.

Flexibility of sand casting is often important. Changes can be made in the design of a casting and new parts produced faster because the sand molds can be modified faster than metal molds.

INGOT CLASSIFICATIONS

Primary Aluminum: Molten metal in the reduction pot is called "Virgin" metal or "Primary Aluminum".

Primary Aluminum Ingot: Virgin aluminum from the reduction pot, when fluxed, skimmed, and poured into molds, becomes "Primary Aluminum Ingot". The fluxing produces a cleaner metal with less porosity, less foreign matter and fewer gas inclusions.

Aluminum Casting Ingot: Ingot which has been alloyed by adding the alloying elements required so that when remelted by the foundry and poured into molds, the casting will have the desired composition.

Alloy Hardener Ingot: Certain foundries prefer to buy pure metals and do their own alloying. However, some elements are difficult to put into solution in the pure form, so the element is put into the melt by adding aluminum containing a high percentage of the element desired. Such material is called "Master Alloy" or "Hardener".

Size Explanation: Note that the various types of ingot can be cast into any desired size. Ingot is normally supplied to the foundry industry as 50-pound unnotched castings, but can be supplied up to 1000-pound units. Ingot is ordinarily produced in 30-pound size or smaller. These are usually notched for ease in breaking.

The term "Aluminum Pig" is no longer used, so that definition has been omitted deliberately in this summary of classifications.

Non-Heat-Treatable Alloys: Aluminum Casting Ingot can be broken down into groups, according to whether or not the mechanical properties of the material can be improved by heat treatment. Alloys generally regarded as non-heat-treatable include 12, 13, A13, 43, 108, A108, 112, 113, C113, 138, 212, 214, A214, B214, F214, L214, 218, A218, 360, A360, 380, A380, 384, Almag 35, 603, 604, 607, D612, and 613.

Heat-Treatable Alloys: Aluminum Casting Ingot generally regarded as heat-treatable includes alloys 122, A132, D132, Z132, 142, A142, 195, B195, 220, 319, A319, 333, 355, C355, 356, A356, 357, A357, 750, and TENS 50.

Sand-Casting Alloys: Aluminum Casting Ingot can also be grouped according to the type of casting method for which the alloy is suitable. Thus alloys generally regarded as suitable for sand casting include 12, 43, 108, 112, 113, 122, 142, A142, 195, 212, 214, B214, F214, A218, 220, 319, 355, C355, 356, A356, 357, A357, Almag 35, TENS 50, 603, 604, 607, D612, 613, A750.

Permanent-Mold-Casting Alloys: Aluminum Casting Ingot generally regarded as suitable for permanent-mold casting includes alloys 43, A108, 113, C113, 122, A132, D132, 138, 142, A142, B195, A214, 319, 333, 355, C355, 356, A356, 357, A357, 382, TENS 50, 750, A750, and B750.

Die-Casting Alloys: Aluminum Casting Ingot generally regarded as suitable for die casting includes alloys 13, A13, 43, 85, L214, 218, 360, A360, 380 (AXS-679), A380, and 384.

Alloy Designation System: The alloys are designated by a number arbitrarily assigned. The addition of a letter simply means that such an alloy differs slightly from the basic composition indicated by the number. See Reynolds "THE ALUMINUM DATA BOOK" for temper designation system.

EFFECTS OF ALLOYING ELEMENTS

In foundry work additional elements are added to pure aluminum to improve foundry characteristics, such as to increase the fluidity, reduce hot shortness, and the like; or to provide certain desired characteristics in the finished casting, such as increased corrosion resistance, strength, machinability, weldability . . . or to make the casting susceptible to heat treatment.

Elements most commonly added in aluminum casting alloys include silicon, copper, magnesium, titanium and boron. Other elements less commonly added include manganese, zinc, nickel, chromium, tin, iron, sodium, beryllium, etc.

Individual alloying ingredients must be selected and combined to produce the desired casting characteristics and mechanical properties. Where an element is advantageous in one alloy, it can be detrimental in another. A balance must always be worked out.

Silicon (Si) improves the fluidity of the molten aluminum, allowing it to flow farther through thin walls in the mold cavity and reproducing finer details. It also reduces external shrinkage, decreases leaks in the finished casting, reduces the coefficient of expansion and improves weldability.

Preferably, the silicon should be present in the casting in the modified form; that is, rounded shapes and widely dispersed. When present as primary

crystals or small plates in the casting structure, it causes these to act as stress raisers and thus is detrimental to obtaining maximum mechanical properties in the casting. It also decreases machinability. This tendency to revert to primary crystals increases with higher silicon contents and with slower cooling rates or by holding in the molten state for an extended period of time. Frequently it is necessary to slightly modify the silicon by treating with sodium to get the desired effects. Reynolds pig and ingot are sodium modified.

Thus only those alloys intended specifically for die casting (with exceptions such as D132, A132, etc.) can support the high ranges of silicon (8 to 12 percent), because only in die casting is chilling sufficiently rapid to obtain a modified structure.

Copper (Cu) is one of the principal hardening constituents in aluminum casting alloys today. It increases the strength of alloys in both the heat-treated and non-heat-treated conditions. Copper is quite soluble in aluminum at elevated temperatures (5 percent at 977°F), and just slightly soluble, approximately 0.1 percent, in aluminum at room temperatures. The difference in solubility at varying temperatures is the characteristic that makes aluminum alloys heat treatable.

With the exception of 355 alloy, the alloys that are heat treatable fall largely into two groups. One group employs 3-5 percent copper along with other elements that provide controlled solid solubility . . . the second group employs 7-11 percent copper along with other elements such as 122, and C113 alloys.

Copper reduces internal shrinks and improves machinability in the castings. However, copper additions make the alloy more difficult to cast than silicon additions because of hot shortness and decreased fluidity.

Copper in an aluminum casting reduces its corrosion resistance severely due to the galvanic reactions set up between the copper-rich particles of the constituent and the aluminum matrix, when moisture is present. Thus in damp, salt atmosphere, pitting and corrosion products are the result. Corrosion rates increase rapidly from approximately 0.3 percent copper up.

Magnesium (Mg), like copper, has the solid solubility characteristics required to make an alloy heat treatable. Aluminum alloys containing over 8 percent magnesium will respond to heat treatment. Alloys with less magnesium are not heat treatable unless some other alloying element (such as copper or silicon) are also present.

Magnesium additions make the metal more difficult to cast because of drossing tendencies. Pick-up of iron, silicon, copper, or other elements is very detrimental to the properties of the straight binary aluminum-magnesium alloys. This problem becomes more serious as the magnesium is increased. For these reasons, special care is required when handling the straight aluminum-magnesium alloys in the foundry. Reynolds ingot includes beryllium additions (Patented Process) which tend to reduce drossing in high magnesium alloys. For best results, it is necessary to flux with chlorine gas to remove oxides generated during remelting.

Magnesium additions provide both increased strength and ductility, increase corrosion resistance (under certain conditions), and improve machinability.

Titanium (Ti), usually added as a grain refiner to all casting alloys intended for sand or permanent-mold castings, is desirable to improve the mechanical properties of the castings. Titanium is not added to die-casting alloys as their fast cooling provides an inherently fine grain. Also grain-refined metal is slightly less fluid and so might lead to difficulties in die casting. Titanium makes castings that have decreased thermal conductivity, but improved tensile strength and ductility.

Boron (B) gives good grain refining action when used with titanium. Without the benefits of boron, the grain refining effects of titanium are reduced in remelting. Boron also improves tensile strength and ductility.

Miscellaneous Alloying Elements employed in aluminum casting alloys include iron, manganese, chromium, nickel, zinc, tin, beryllium, and lead.

Iron (Fe) additions are sometimes employed to reduce shrinkage and to act as grain refiners. However, high iron in silicon alloys above 0.5 percent results in coarse crystals and a brittle structure. Sometimes 0.80 percent iron is desirable with silicon alloys of 8 percent or more because it tends to eliminate welding of the dies in pressure castings.

Manganese (Mn) additions act as a grain refiner and reduce shrinkage. When added to both copper and silicon alloys, manganese improves the strength of castings in high temperature applications. However, manganese must be controlled in combination with iron or the reverse effects will result.

Chromium (Cr) is primarily a grain refiner used with titanium additions, such as in A142 alloys. It may also be added to reduce stress cracks or stress corrosion. In certain alloys it may be added to improve strength at elevated temperatures.

Nickel (Ni) improves dimensional stability and strength at elevated temperatures. It is always used in combination with other alloying elements. Air-cooled aircraft engine cylinder heads and pistons for internal combustion engines find nickel additions particularly valuable.

Zinc (Zn) added to aluminum makes the metal very hot short and produces high shrinkage when used in large amounts. Exceptionally fast melting is necessary to obtain best characteristics. Likewise, large risers are important. Zinc additions produce good impact resistance, high tensile strength, and excellent ductility, particularly in such alloys as D612 and 613. Small amounts of zinc in the copper alloys help improve machinability.

Tin (Sn) is fairly easy to add after the metal becomes molten, although considerable stirring is necessary because of density. It is used to improve the machinability of the copper alloys. Also it acts to provide a fine bearing alloy when used in conjunction with copper and nickel additions.

Beryllium (Be) reduces drossing when pouring the high magnesium content alloys. This prevents loss of magnesium by burning out in melting operations.

Lead (Pb) is difficult to absorb into the bath in its liquid state, primarily because of its high density and limited solubility even in the liquid state. Lead is used as an alloying element because it improves the machinability of the alloy, especially when used along with tin or bismuth.

ALLOY CLASSIFICATIONS

The common aluminum casting alloys contain one or more of the alloying elements previously discussed. Aluminum alloys are divided into two general groups: binary alloys consisting of aluminum and a single, controlled alloying element; and composite alloys consisting of aluminum and two, or more, controlled alloying elements.

The common binary alloys are the aluminum-copper, aluminum-silicon, and the aluminum-magnesium alloys. Typical composite alloys are the aluminum-copper-silicon, aluminum-copper-silicon-magnesium, aluminum-silicon-magnesium, and the aluminum-copper-nickel-magnesium alloys.

Binary Aluminum-Silicon Alloys include the sand, permanent-mold, and die-casting alloy 43 with nominal 5.25 percent silicon, and the die-casting alloys 13 and A13 with nominal 12 percent silicon. These alloys permit production of intricate castings with thick and thin sections; machine readily although not as easily as some other alloys; provide cast parts that are pressure tight; and offer excellent corrosion resistance. This latter factor has resulted in wide application in the textile industry and like fields where mild acids are encountered. They are also well suited to architectural, marine and household applications. Alloys 43, 13, and A13 are non-heat-treatable alloys.

Binary Aluminum-Magnesium Alloys include 4, 8, and 10 percent magnesium which are known as 214, 218, and 220 alloys respectively. These feature an excellent combination of mechanical and chemical properties. They are especially resistant to corrosion and tarnish, being superior to practically all other common aluminum casting alloys in this respect. They even exceed the aluminum-silicon alloys in their resistance to marine atmosphere and mildly alkaline solutions. These alloys offer good machining characteristics. They can be as easily welded as other aluminum casting alloys with Heliarc or similar equipment for shielded inert-gas metallic-arc welding.

The aluminum-magnesium alloys offer excellent mechanical properties also. For example, among highest mechanical properties of any of the aluminum sand-casting alloys are those of alloy 220 . . . minimum tensile strength 42,000 pounds per square inch (ultimate), and 12 percent elongation. It is not unusual to obtain 55,000 psi and 25 percent. In fact, 46,000 psi tensile and 14 percent elongation are considered typical values for alloy 220-T4.

Alloy 220 has its best mechanical properties, highest corrosion resistance, and greatest temperature stability when in the solution-heat-treated condition ("-T4"). For this reason, alloy 220 should not be artificially aged or used where working temperatures are above 250°F. While alloy 220 is heat treatable, alloys 214 and 218 are not.

Aluminum-Copper-Silicon Alloys can be divided into three groups according to copper content; those with nominal 3.75 percent copper include 85, 108, 319, A319, 333, 380, A380, and 384. Alloys with 4.5 percent copper include A108 and B195. Those with 6 to 8 percent copper include 12 and C113. These alloys have almost completely replaced the original binary alloy of aluminum and copper with the exception of 195 alloy. Alloys in

this classification are characterized by improved machining qualities. Those with high silicon contents provide the high fluidity required for castings with moderately thin sections.

Alloys B195, 319, A319, and 333 are heat treatable. Other copper-silicon alloys (12, 85, 108, A108, C113, 212, 380, A380, 384) although responding to heat treatment, are not normally considered heat treatable alloys and are usually used in the as-cast condition.

Alloys in this classification considered as sand-casting alloys are 12, 108, and 319. Those regarded as suitable for permanent-mold casting are A108, C113, B195, 319, and 333. Those suitable for die-casting work are 85, 380, A380, and 384.

Aluminum-Silicon-Magnesium Alloys include 355, C355, 356, A356, 357, A357, 360, A360, and 382. These also can be grouped according to magnesium content as follows: 355, 356, 360 and A360 with roughly 0.2 to 0.7 percent magnesium and 382 with 1.7 to 2.5 percent magnesium. Silicon content is specified for various ranges from 5.0 for 355 to 9.5 for 360 and A360.

Alloys in this classification possess the highly desirable features of castability, pressure tightness, strength, and corrosion resistance. Alloys 360, A360 and 382 are not heat treatable. Improved mechanical properties can be obtained by suitable heat treatment of alloys 355, C355 and 356, A356, 357, A357, and TENS 50, the only heat-treatable alloys in this classification. See Reynolds handbook, "Aluminum Heat Treating".

Aluminum-silicon-magnesium alloys suitable for sand casting are 355, C355, 356, A356, 357, A357, and TENS 50; for permanent-mold casting . . . alloys 355, 356, and 382; for die casting . . . alloys 360 and A360.

Aluminum-Silicon-Nickel-Copper-Magnesium Alloys A132, D132 and Z132 provide a unique combination of properties. These alloys are particularly suited for pistons for internal combustion engine because of their low thermal expansion and excellent dimensional stability. These alloys retain their strength well at elevated temperatures and possess good resistance to wear.

All the alloys in this classification respond to heat treatment and are usually employed in the heat-treated condition. These alloys are used primarily for permanent-mold casting.

Aluminum-Copper-Nickel-Magnesium Alloys are another class widely used for their good high-temperature characteristics. Alloy 142 ("Y" alloy) and A142 are in this group. In addition to retaining strength at elevated temperatures, castings of these alloys also possess good resistance to wear. These alloys are similar in characteristics to the aluminum-silicon-nickel-copper-magnesium alloys mentioned in the previous section, and in addition have improved machinability, but slightly higher thermal expansion.

Alloy 142 and A142 provide high mechanical properties and dimensional stability upon suitable heat treatment. They can be cast either as sand castings or permanent-mold castings and are used predominately in pistons and cylinder heads.

ALUMINUM CASTING PROCESSES

The three processes in most general use are sand casting, permanent-mold casting and die casting. Plaster casting, centrifugal casting, investment or precision casting, slush casting, and a few other methods are also in limited use.

A knowledge of the limitations and advantages of the various casting methods is essential for selecting the process best suited to the product. Once the casting process is chosen, changes may be needed in the design of the product, for different design limitations are imposed by the different casting methods. Generally the quantity of castings required is the determining factor in selecting the casting process.

Die casting gives the highest production rate, with permanent mold next, and sand casting the lowest. Metal dies are much more expensive than sand molds. Consequently, die casting or permanent-mold casting can give low unit costs only where quantities are sufficient to allow the high tooling costs to be divided over a large number of castings. However, the costs of metal-mold casting often can be justified on the basis of closer dimensional control which cuts the machining and finishing operations usually needed on sand castings.

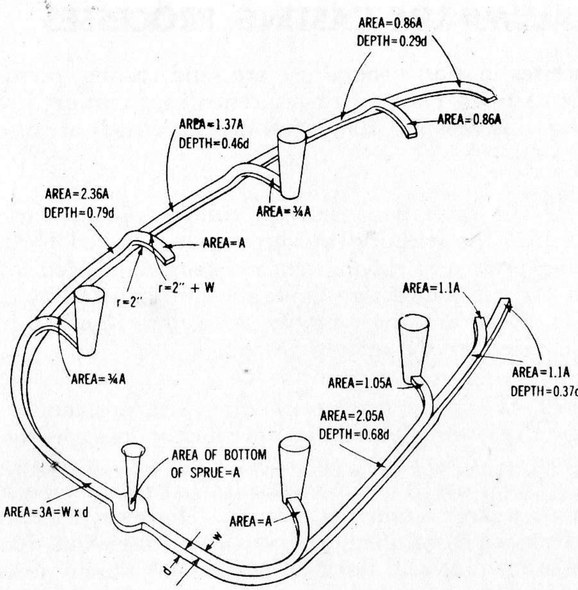
SAND CASTING

Sand castings have the lowest initial cost and permit flexibility in design, choice of alloy, and design changes during production. For these reasons, sand casting is used to make a small number of cast pieces, or to make a moderate number that require fast delivery with little likelihood of repeat production. Large castings, and those with intricate coring, are also sand cast. A sand-cast part will not be as uniform in dimensions as one produced by other casting methods, so greater machining allowances must be made. Surface finish can be controlled somewhat by varying the quality of sand in contact with the metal and by applying special sealers to the sand surfaces.

Sand molding methods used with other metals need but slight modification to make good aluminum castings. Handling and conditioning of sand, core fabrication, and most molding practices remain the same. On the other hand, properties peculiar to aluminum alloys do give rise to certain preferred molding practices.

Aluminum's light weight—one-third that of cast iron, steel, or brass—lowers mold pressures and necessitates lighter sand ramming. Weights are not required when pouring small or medium-sized molds; in fact retaining boxes and frames often are not even needed for such molds when made in snap flasks.

The advantages of light weight are partially offset by the fact that the low density of the molten metal increases the difficulty of eliminating oxides and



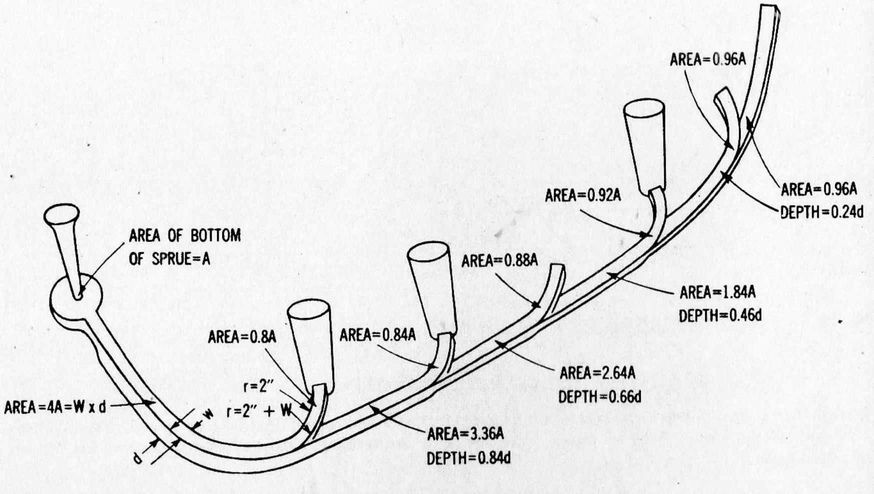
Design of a typical irregular two-runner gating system recommended for aluminum castings by Battelle Memorial Institute in its "foundry manual" (PB 111577) prepared for the Frankford Arsenal.

mold gases. Heavier metals drive off mold gases and rid themselves of oxides without special precautions. With aluminum alloys, it is necessary that the melt be delivered to the mold with minimum oxide by thorough fluxing in the ladle, preferably with chlorine gas. In addition, high-permeability sand is needed to allow escape of air, water vapor, and mold gas. Lighter sand ramming will aid in assuring sufficient permeability.

Hot Shortness: Certain alloys have low strength at temperatures just below solidification. The casting may crack if these alloys are cast in a mold that offers resistance to contraction as the metal solidifies. This is called "hot cracking" or "hot shortness". The aluminum-silicon alloys show considerably less hot shortness than aluminum-copper alloys. The wide range of aluminum alloys available enables the designer to choose an aluminum alloy and avoid hot cracking where this factor is important.

Solidification Shrinkage: Aluminum alloys also have an appreciable solidification shrinkage which occurs as the metal changes from the molten to the solid state. Compensation for this shrinkage must be made to achieve the desired final dimensions, and to prevent shrinkage porosity and shrinkage cracks.

Those aluminum alloys solidifying over the widest temperature range (such as the aluminum-copper alloys) shrink the most. These alloys require more feeding to overcome the effects of shrinkage. Those with a narrow solidifi-



Single runner and gate system for casting aluminum in which the flow capacity of each of the five gates is approximately the same . . . as recommended by Battelle Memorial Institute to Frankford Arsenal.

cation temperature range (such as the aluminum-silicon alloys) require less feeding. Proper gating and risering (or heading) will help overcome solidification shrinkage.

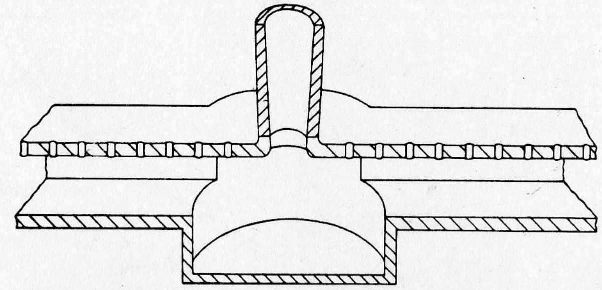
Gates and Risering: Additional molten metal must be fed in from the risers to reduce the effects of solidification shrinkage. Sufficient risers must be provided. See illustrations on Pages 11, 12, 13, and 14.

Redesign and relocation of the gates feeding a previously improperly gated casting has increased the strength of the casting as much as 50 to 100 percent. The molten aluminum alloy must enter the mold cavity through multiple gates, not merely through one point as is sometimes done with other metals.

In general, aluminum castings need larger gates and risers than other metal castings. Thus the average weight of metal poured is about two to three times the weight of the finished casting.

Sand Selection and Control: Both natural and synthetic molding sands, with a wide range of physical properties, are available for use with aluminum alloys. Where a smooth cast surface is desired, a naturally-bonded fine-grained sand having a high clay content is used. This type sand is also best when mechanical reconditioning equipment is not available.

Typical properties of this type of natural sand are: green compression strength, 5-8 psi; permeability, 5-30; clay content, 10-25 percent; grain fineness number, 140-270; moisture content, 4.5-6.0 percent. A sand of this fineness must be reconditioned properly before reuse. The moisture content must be closely controlled when casting aluminum, otherwise the low permeability will induce gas porosity and blows.



Design for a sprue base as recommended by Battelle Memorial Institute to Frankford Arsenal. The well slows down flow of metal from sprue to runners, minimizes turbulence and aspiration of mold gases.

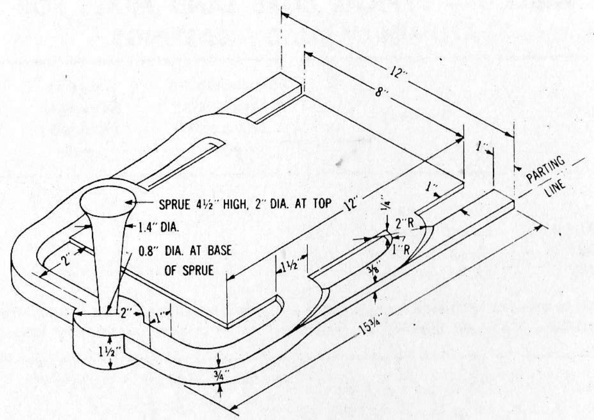
Sounder casting will result if the surface requirements of the castings permit the use of a coarser grade of sand—one having a permeability of 25 or higher. Such coarser sands can be bonded naturally. However, they are better when prepared with bentonite added to a silica sand or to molding or bank sand of low clay content.

A satisfactory synthetic molding sand will have the following properties: green compression strength, 6-10 psi; permeability, 25-120; clay content, 3-10 percent; grain fineness number, 70-160; moisture content, 2.5-3.5 percent. Synthetic molding sands should be mixed thoroughly by a suitable "muller" to insure uniform distribution of the ingredients and proper development of their physical characteristics. Natural molding sands only require mixing before use to adjust their moisture content to optimum value.

Reconditioning of natural sands can be accomplished by hand mixing, but their useful life will be extended by the use of mechanical mixing and aeration done as often as possible. Synthetic sands must be mixed mechanically after each use. This is necessary because the prepared clay bonds of synthetic sands lose their plasticity after contact with molten metal. Intensive mixing, and the replacement of lost moisture content and burned out clay are needed to redevelop the physical properties of the sands.

Cores for casting aluminum are made of either silica sands or bank sands, or mixtures of them, together with bonding materials and water. Vegetable drying oils, petroleum derivatives, resins, cereals, proteins, pitch, or combinations of these materials are the most commonly used core binders.

Refractory core washes and core sprays are applied in liquid form to improve the surface finish of the core and to reduce the effects of core gases. Graphite or talc, in either water or a volatile liquid, are regarded as best. Chlorinated rubber carried in a toluene solution or a water solution of ammonium fluoborate is used on deep thin sections, such as air-cooled cylinder fins. See Table 1, Page 15.



Gating system for casting flat aluminum plate as recommended by Battelle Memorial Institute to Frankford Arsenal. Notice tapered sprue, multiple gates, elimination of right-angle corners in sprues and gates. Runner extends past last gate to trap dross and prevent backlash of first metal poured. Runners are in drag; gates in cope.

Permanent-Mold Casting

In permanent-mold casting, the molten aluminum alloy is poured by gravity into heated metal (permanent) molds, requiring a different arrangement of foundry equipment, handling methods, and production procedures as compared to sand casting.

A simple, permanent mold usually consists of two metal halves which, when closed, form the mold cavity. Either metal or sand cores can be used (designated as semi-permanent mold casting when sand cores are used). The mold is heated before pouring and held at a constant temperature during pouring. Some castings require either heating or cooling of the mold between pouring operations; others are so arranged that the molten metal keeps the mold at the desired temperature.

With permanent-mold casting, a carefully established and rigidly maintained sequence of operations is essential. Every step in the foundry, from charging the furnace to removal of the cast piece from the mold, must be systematized. If any of the factors are thrown out of balance, the resultant castings may end up as scrap.

Casting Characteristics: The improved mechanical properties of permanent-mold castings are the result of the advantageous crystalline structure that

TABLE 1 — TYPICAL CORE SAND MIXES FOR ALUMINUM ALLOY CASTINGS

Sands (Dry)	Binders	Compressive Strength (Green) psi	Tensile Strength (Baked) psi	A.F.A. Permeability
1000 lb. Washed Silica Sand, A.F.A. Grain Fineness Number, 55-80	10 lb. Cereal flour 2-5 qt. Core oil 3 qt. Kerosene 18 qt. Water	0.6 to 0.9	125 to 225	70 to 160
A general purpose mix for large and small cores requiring smooth surface, moderate green strength, high permeability. Vary oil content as indicated to obtain required dry strength.				
1000 lb. Washed Silica Sand, A.F.A. Grain Fineness Number, 60-65	12 lb. Cereal flour 11½ lb. Urea Formaldehyde binder 13 qt. Water 2 qt. Kerosene	0.75	180	160
A general purpose bench mix, particularly useful for cores when easy knock-out characteristics are required.				
1000 lb. Washed Silica Sand, A.F.A. Grain Fineness Number, 60-65	10 lb. Cereal flour 4 qt. Core oil 5 qt. Kerosene 12 qt. Water	0.75	190	175
A core mix having the free flowing and nonsticking characteristics required for use in blowing machines.				

Above data from "Recommended Practices for Sand Casting Aluminum and Magnesium Alloys", published by American Foundrymen's Society.

develops in the cast alloy as it cools and solidifies rapidly in the metal mold. Permanent-mold castings have closer dimensional tolerances and smoother surfaces than are possible to obtain in sand castings. So less machining and finishing are needed.

Because of the higher mechanical strength of these castings, thinner sections can be used thereby reducing the weight of the piece which usually ranges from a few ounces up to 20 pounds or more.

Extremely hot-short alloys, or ones with high solidification shrinkage, should not be used because of the resistance of the metal mold. Sand cores partially alleviate this condition, but it is best to avoid trouble by using only the alloys recommended for this casting method.

Gating and Risering: The longest dimension of a permanent-mold casting

is usually vertical, as contrasted to horizontal positioning when sand casting. Sprues, risers, gates, and runners must all be designed as part of the mold structure. The difficulty and expense of making radical changes in metal molds make it essential that the entire feeding system of the mold be finalized before the mold is made.

It is wise to build a mold with initially undersized gates and risers. Then, by making experimental castings, gradually increase the size of the feed channels until the best possible casting is obtained. This obviates the possibility of having over-sized channeling to begin with, and minimizes the amount of metal to be poured.

Mold Preparation: Using coatings of refractory material, the solidification rate in different sections of the mold can be controlled by varying the coating thickness; and the mold metal is protected from direct contact with the molten aluminum. Solidification will start at those sections where the coat is thinnest, due to the faster heat dissipation at those points.

The refractory coating is applied heavily along thin sections and through the gates and risers. Thin coats are used on areas of wide cross-sections to promote faster solidification there. By applying the coating to the proper thickness the rate of solidification throughout the casting can be made uniform. The coating can be formulated from almost any refractory material finely ground in a water suspension with a suitable binding agent.

To avoid coating wear or abrasion when the mold is opened or when the casting is lifted out, the mold surfaces are arranged so they leave the surfaces of the casting at angles of from 45 to 90 degrees when opening the mold. If this cannot be done, the mold surfaces subject to abrasion should be readily accessible to allow renewal of the coating whenever necessary.

Die Casting

In this method the molten aluminum alloy is forced into a metal mold under considerable pressure. Die casting gives low cost production of large numbers of thin sectioned parts. Close tolerances and extremely smooth surfaces can be produced without subsequent machining and finishing, also small complex coring is possible, saving many drilling operations. Such coring is not possible in sand or permanent-mold casting. Intricate parts, not practical with other casting methods, can be produced easily by die casting.

Satisfactory die casting depends on a suitable die-casting machine; and a properly designed die. The die-casting machine consists of a substantial, rugged frame designed to support and open the die halves in perfect alignment. The two halves of the die must move together accurately and must be locked together with sufficient force to overcome the separating force developed as the metal is injected.

Most dies also have moving cores and other features which allow the production of complex castings. The cores, slides, and other moving die parts are operated by hydraulic action synchronized with the opening and closing of the main die halves.

Metal Injection: Molten aluminum alloy is introduced into the die cavity by means of either the "goose neck" or the "cold chamber" method. In goose neck injection, the molten aluminum alloy is forced into the mold by means of pneumatic pressure exerted on the surface of the molten metal.

In cold chamber injection, a hydraulically actuated plunger forces the molten metal from a cylindrical "shot" sleeve into the mold. The process is designated as "cold chamber" because the molten alloy is ladled into the shot sleeve just before it is forced into the mold. Pressures in the two methods vary: the goose neck method is usually about 750 psi, while the cold chamber method runs 3,000 to 20,000 psi.

Metal enters the die in the cold chamber process in a semi-molten condition thereby forcing the air out ahead of the metal. In the "goose neck" system, the metal enters the mold in a completely molten state and tends to mix with air in the die cavity. This tendency to produce porous castings has resulted in goose neck equipment becoming obsolete. It has now largely been replaced by cold chamber machines.

Heat-treated alloy steel dies are needed for die casting aluminum. Initial tooling cost is high but the productivity of a die-casting machine is high so that low unit cost can be obtained where the production run is long.

Centrifugal Casting

Centrifugal casting entails pouring a measured quantity of molten aluminum alloy into a mold which is then rotated rapidly. The rotation of the mold forces the molten metal outward to give intimate contact between the metal and the mold. Spinning is continued until all the metal poured in the mold has solidified. Pouring must be done quickly to prevent chilling and laps.

Most aluminum casting alloys suitable for the other processes can be used for centrifugal casting. The alloys should be poured at about 100°F less than with static casting. Alloys with short solidification ranges are preferable to those with wide freezing ranges.

In true centrifugal casting the mold is rotated about its own axis without using a central core. If the mold is partially filled, a hole will appear along the center of rotation of the casting, the diameter of the hole being determined by the amount of metal used. The weight of casting produced to that of metal poured approaches a 1:1 ratio in this method.

In semi-centrifugal casting, central cores are used to give irregular shapes to the central hole. A measured amount of metal is poured so the mold space between the core and the outer wall is filled completely. Proper design of the mold is essential so that directional solidification of the metal is retained.

Sand or plaster cores are usually employed. Differentially heated or cooled outer molds may be needed to control the direction of solidification.

In centrifugal casting, irregular shapes can be obtained that would not be possible if the parts were rotated on their own axis. In this process a number of molds are arranged about a central sprue like the spokes of a wheel. Molten metal is fed into the castings through radial gates.

Plaster-Mold Casting

This is a refinement of sand casting in that the sand is replaced by plaster, giving the finished casting a smoother surface and allowing greater accuracy in dimensions of the molded part. A plaster mold will make just one casting since it is necessary to destroy the mold to remove the casting. The process is usually confined to castings under 2 pounds. Gypsum plasters are the preferred type.

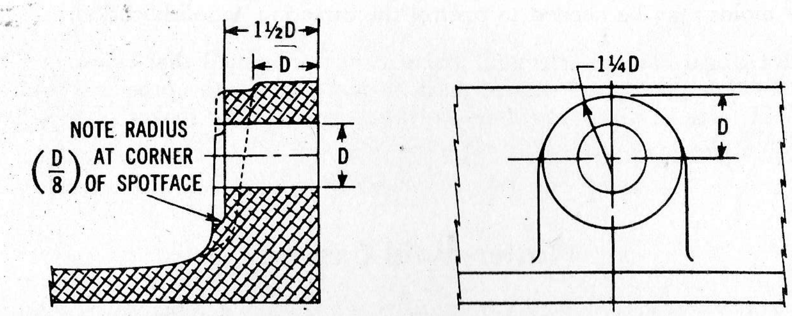
The aluminum alloys used with plaster molds must be carefully selected. The refractory nature of the plaster results in a slow solidification time with resultant lowering of mechanical properties. This refractory quality, however, enables thin and intricate sections to be cast. Due to their excellent fluidity, the aluminum-silicon alloys are the best ones for plaster casting.

Precision Investment Casting

This method, based on the "lost wax" process, allows for the intricacy of design of sand casting, and the precision of die casting. To make a mold, a refractory type plaster is poured around an expendable wax pattern. After the plaster sets, it is dried in an oven and the wax pattern melted out. As in plaster casting, the molds are used only once since they must be broken to remove the casting. A refinement of this process is the substitution of frozen mercury for the wax.

A master mold is required to make the wax patterns. The number of castings required will determine the permanency of the master mold. When large numbers of castings are to be made, the master molds should be made of metal, and an injection molding process should be used for the production of the wax patterns. This process is expensive due to the number of steps required, the need for skilled operators at each step, and the slow production rate compared to other casting processes. The use of plaster molds causes slow cooling and limits the choice of aluminum alloys to those suited to plaster casting.

The molten aluminum alloy is poured under pressure and extremely sharp details can be obtained in the cast piece. The accuracy of this process is very high . . . even greater than that achieved with die casting because there



Here is another detail as suggested by the American Foundrymen's Association for aluminum castings with a flange carrying a bolt hole.

are no moving parts in the plaster mold. Naturally, the ultimate accuracy of the method depends on the accuracy of the master mold used to make the wax patterns. Because of the slow cooling of this type casting it is imperative that the metal be thoroughly fluxed with chlorine gas in order to eliminate pinhole porosity.

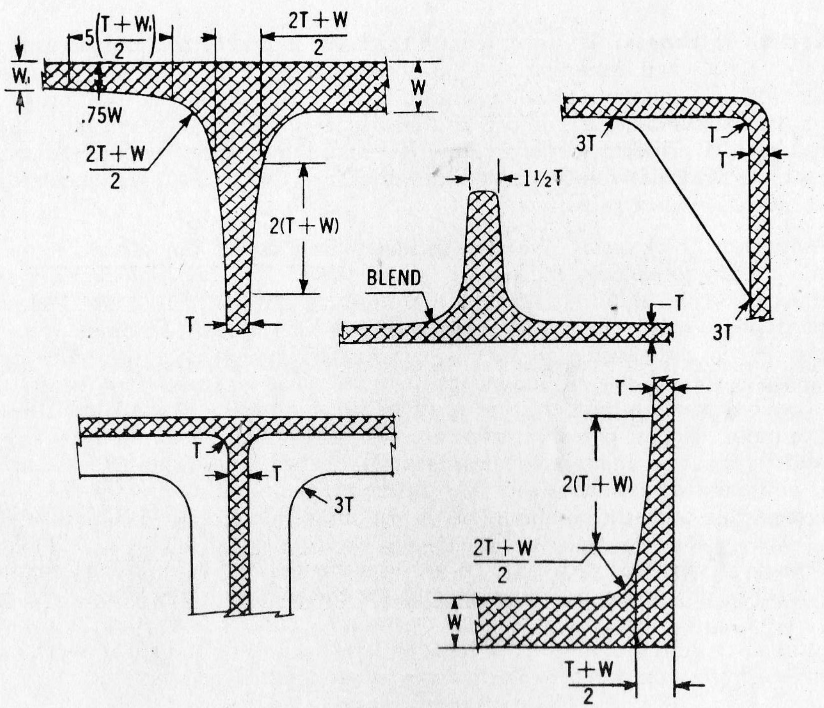
SELECTING THE ALLOY

When choosing an alloy, the following factors must be taken into consideration:

Mechanical Properties will usually determine whether or not the alloy is to be heat-treatable. High strength requirements necessitate the use of a heat-treatable alloy. In certain applications, special requirements, such as extreme hardness, high impact resistance, or dimensional stability, will decide which alloy is to be employed.

Physical Properties must be considered in special applications where high electrical or thermal conductivity, good corrosion resistance, low thermal expansion, or certain other properties are needed.

Foundry Characteristics are especially important if a large or intricate casting is involved. The size and shape of the part to be cast determine the required foundry characteristics. For instance, if the casting has thin sections, an alloy with good fluidity must be selected. Moreover, for castings of intricate shape, together with thin sections, an alloy having both good fluidity and high resistance to hot cracking must be used. In many cases, it is impossible to find an alloy with all the particular requirements for a certain application. As a result, the final selection of the alloy will be a compromise between the properties required and those actually obtainable.



These are designs suggested by American Foundrymen's Association for joining walls in aluminum castings.

Refer to "The Aluminum Data Book" for the relative corrosion resistance, fabricating characteristics, and mechanical properties of the casting alloys.

ALUMINUM CASTING DESIGN

The design of aluminum castings involves the consideration of many factors, including the casting method and the aluminum alloy to be used, as well as design details of the cast piece. Such details include section thicknesses, rib design, fillets, blending, finishing allowances, locating points, allowances for draft and shrinkage, and the like.

In some cases the functional requirements and the appearance of the finished product will be the determining factors. In other cases foundry and economic considerations will be the most important factors influencing the design of the casting.

Section Thickness: Uniform section thickness should be maintained as much as possible when designing an aluminum casting. This simplifies gating and feeding and equalizes the rate of solidification. Unequal solidification causes uneven solidification shrinkage and may leave shrinkage voids in the finished casting. If uniform sections cannot be maintained, thin sections should be increased gradually so they blend into thicker sections without having extreme variations in close proximity.

Minimum Thickness: The size, intricacy, and use of the casting influence the minimum section thickness. In any case, the section thicknesses used must have the required strength. Aluminum alloys can be cast in sand or permanent molds in minimum sections ⅛-inch thick. Thinner walls are possible in die castings, if they are favorably located with regard to gates. Sections should not be made at the minimum thickness if it means that excessive pouring temperatures must be used to ensure proper flow through the mold. Actual pouring temperature is determined by the thinnest section and its location relative to the gates. It is always desirable to pour at the lowest possible temperature. The optimum temperature thus is the lowest compatible with the requirements of the minimum section thickness.

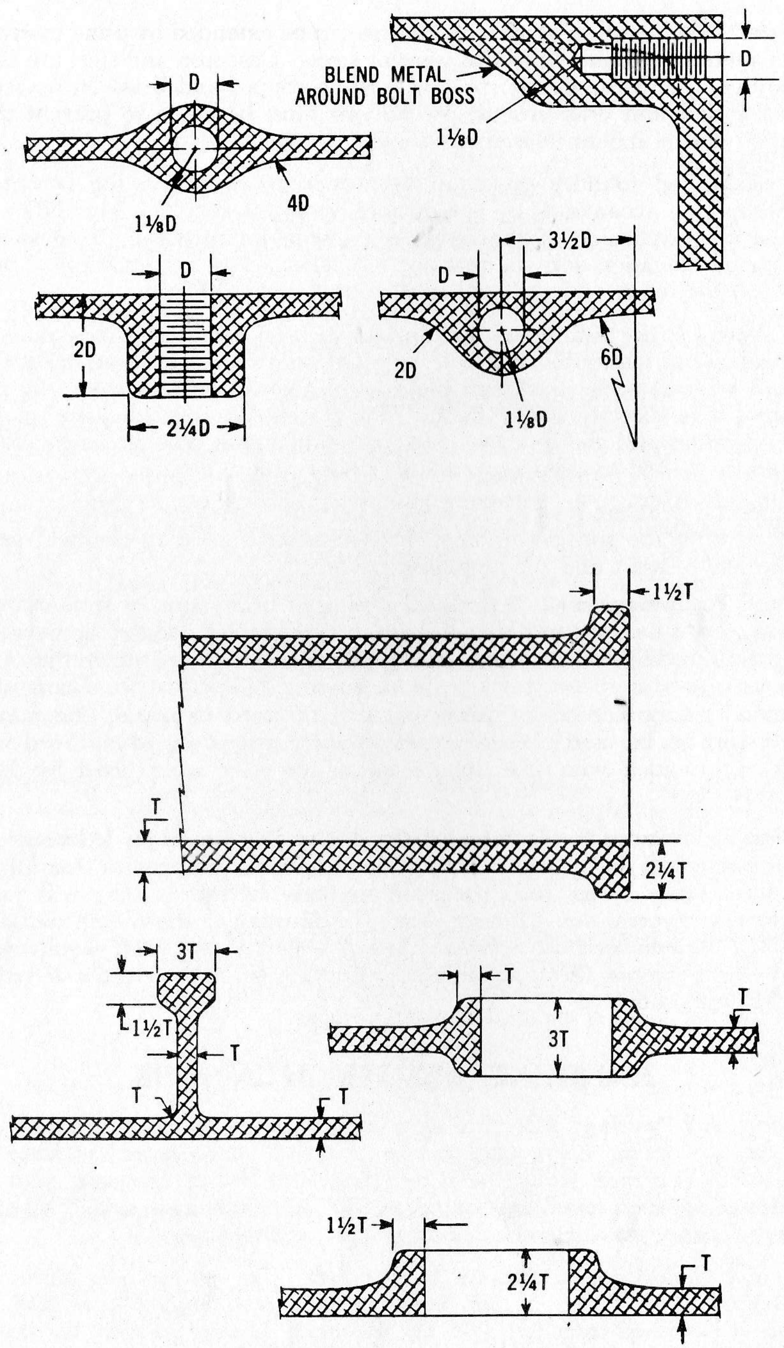
Ribs are provided in castings to act as stiffeners and reinforcing members. An ideal rib should be about as thick as the section it reinforces. Thinner ribs set up casting strains due to their high cooling rates. Cracks and impaired strength can result. A flat edge on the top of the rib reduces outer fiber stresses compared to the stresses in rounded or pointed ribs.

A beaded edge on the top of the rib will reduce possible stresses to a minimum. So beads should always be used unless they complicate the molding operation. Whenever possible, ribs should be cast in the drag or bottom part of the mold. This reduces the possibility of unsound ribs, and prevents the accumulation of dross and dirt in the rib.

Fillets and Blending: Ample fillets and blending are needed to provide more even distribution of applied loads when the casting is put in service. In addition, they minimize shrinkage and cracking during casting. Poorly filleted ribs are the cause of many defective castings.

Sizes of fillets depend on the shape and thickness of the adjoining wall sections and the size of the casting. When joining sections of unequal thickness, the fillet radius should be based on the mean of the two. If the thickness of the larger section is more than 1½ times that of the smaller section, the filleting must be further extended by blending.

Shrinkage: With aluminum alloys, shrinkage ranges from 5/32-inch per linear foot, where minimum shrinkage resistance is encountered, down to 1/10-inch per foot where considerable resistance is offered by projections and cores in the mold. The shrinkage for any particular casting can only be worked out by experimental runs in the foundry. These may indicate changes in the mold design . . . or even in the casting alloy.



Above details suggest proportions recommended by American Foundrymen's Association for aluminum castings with flanges, bosses, and bolt holes.

Inserts: The life of an aluminum casting can be extended by using inserts of other metals at points subject to wear or stress. Cast iron and steel are commonly employed for this purpose as well as copper and brass on occasion. With copper and brass inserts, precautions must be taken to prevent their solution in the molten aluminum alloy.

An established foundry procedure is needed to overcome the two main problems that accompany the use of hard-metal inserts: (1) The difference in thermal expansion of the insert and the aluminum can cause stresses during solidification and contraction; (2) The lack of a metallurgical bond between the insert and the casting alloy can cause difficulty.

To allow for the differences in thermal expansion, some inserts must be preheated and inserted in the mold hot. Others are placed in the mold, then heated with a torch. Sufficient metal is placed around the inserts by providing risers directly above them. These risers ensure adequate molten aluminum around the insert to prevent solidification cracks. Large inserts should be slotted to keep contraction stresses to a minimum.

The second problem is usually solved by knurling, grooving, keying, or otherwise treating the surface of the insert to assure a good mechanical union between the insert and the aluminum alloy.

Pattern Equipment suitable for sand casting of brass, iron, or steel in many instances can be used to make aluminum castings after slight modification. In general, additional gates and risers will be needed, and some adjustment may be needed in section thicknesses, depending on application. Loose wood or metal patterns, cope and drag patterns of wood or metal, and matchplates can all be used. Wood or aluminum patterns are often faced with steel or provided with steel inserts to reduce wear when used for large quantity runs.

Design Tolerances for Permanent-Mold and Die Castings: Although no fixed limits can be given for all permanent-mold castings or for all die castings, Table 2 has been prepared to show tolerances that will prove suitable for general use. Castings should be designed to the widest tolerances possible. Remember that, although close dimensional and draft requirements can be met, meeting them means increased cost of production and a decreased rate of production.

HANDLING MOLTEN ALUMINUM

Stirring and Pouring: Excessive agitation of the molten aluminum alloy in the furnace during conveyance to the mold will cause excessive formation of oxide. The melt should be stirred from the bottom upward, with the surface of the melt remaining unbroken. Sufficient stirring is usually supplied during fluxing, making mechanical agitation unnecessary.

The melt should not be skimmed continuously. The molten aluminum need be skimmed only twice . . . just before it is removed from the pot, and just before it is poured from the ladle into the mold. During pouring, the stream of molten metal should be kept as broad and short as possible and should be poured into the sprue without splashing or undue agitation. This will minimize dross formation and entrapment of air in the casting.

Melting Precautions: The aluminum used for charging the furnace should be examined beforehand for suitability and condition. The presence of oil, grease, dirt, or moisture, or the inclusion of a considerable amount of scrap may require preheating or a separate melting to prevent excessive gas absorption. Preheating will usually prove effective for driving off moisture and other volatile material likely to cause trouble. Separate melting of scrap (with accompanying fluxing and skimming) and casting the cleaned melt into ingots will prevent the accumulation of gas and dross in the final melt.

Fluxing is intended to aid the foundry in the elimination of gas and dross from the melt. Fluxing will help control oxide formation and gas absorption, but it should not be regarded as a substitute for careful and well executed melting and pouring techniques.

Types of Fluxes: Gaseous fluxes are used to remove dissolved gas and entrapped dross and oxide film. Solid fluxes either form a gas at the temperature of the melt, in which case their action is similar to that of the gaseous fluxes, or they melt and form a liquid coating on top of the melt. The molten flux prevents gas absorption and formation of oxide and permits ready removal of oxide by floating it on top of the melt as a dry powder. Both types must be kept free of moisture and of hydrogen-forming materials.

Fluxing of aluminum alloys must be done while the material is molten at the temperature best suited to the particular flux used. After fluxing, the melt must be allowed to settle for 10-20 minutes while the temperature of the liquid is adjusted to the pouring temperature. The surface of the melt should be skimmed just prior to pouring.

Gaseous Fluxes: Chlorine gas is the most commonly used gaseous flux and is the cheapest and most effective of either gaseous or solid fluxes. The gas is introduced into the melt close to the bottom of the pot by means of a refractory tube (or coated iron tube) connected to a cylinder of gas. The tube should be treated to drive off any moisture before it is put in the melt.

Chlorine provides a mechanical action and a chemical reaction with any absorbed hydrogen to form hydrogen chloride. As the gases bubble to the surface they agitate the melt which allows suspended oxides to float to their equilibrium position on the surface of the melt. The rate of gas delivery should be adjusted so that the surface takes on a gentle rolling action rather than a turbulent bubbling.

Solid Fluxes are commonly used in open-hearth furnaces for the blanketing effect they produce on top of the melt. Generally the metal is melted and heated to 1250-1400°F before adding the flux. However, when melting scrap or metals containing magnesium, it is better to sprinkle the flux over the charge as it is put in the furnace to provide protection for the metal as it melts.

A typical solid flux is composed of magnesium chloride (37 percent) and potassium chloride (63 percent), thickened just before use by adding calcium fluoride (20 percent of the total quantity of flux).

The required amount of flux can be determined by watching its action with

TABLE 2 — PERMANENT-MOLD AND DIE-CASTING TOLERANCES FOR ALUMINUM ALLOYS

SURFACE	PERMANENT-MOLD CASTING	DIE CASTING
Within part of one mold	0.015" plus 0.001" for each linear inch	0.0015" per linear inch but at least 0.003"
Across parting line of mold	0.015" plus 0.002" for each linear inch	0.010" plus 0.0015 per linear inch
Minimum wall thicknesses for spans of: Under 3 inches....0.125" 3 to 6 inches.....0.156" Over 6 inches.....0.188"		0.050" 0.060" 0.085"
Outside draft	1° minimum 3° desired	0.008" plus 0.001" for each inch of surface diameter for each inch of depth
Draft in recesses	2° minimum 5° desired	Twice draft required for outside surface
Draft on cores	½° minimum 2° desired	Under ⅛ inch diameter: 0.020" per inch of depth ⅛-¼ inch diameter: 0.016" per inch fo depth ¼-1 inch diameter: 0.012" per inch of depth Over 1 inch diameter: 0.012" plus 0.002" for each additional inch.
Maximum length of core supported at only one end	10 times diameter of core	Under ¼ inch diameter: 5 times dia of core ¼-1 inch diameter: 8 times dia of core
Minimum diameter of cores	0.25"	0.094"
Maximum number of external cast threads per inch	16	24

NOTE: Values given in this table are furnished as preliminary guides. Actual limits required will vary with each casting design and must be worked out experimentally.

the melt. Stirring the flux into the dross should make the dross powdery or granular and easily removed. Continue to add flux until the dross powders in this manner. The dry granular dross produced by proper solid fluxing can be lifted off the surface with a perforated skimmer.

Other solid fluxes that give good blanketing effects are a mixture of sodium-silico-fluoride (50 percent) and sodium chloride (50 percent) combined with a mixture of potassium chloride (30 percent) and cryolite (70 percent). These are particularly good for fluxing scrap and metal turnings.

The solid fluxes that form gases such as anhydrous aluminum chloride or

anhydrous hexachloroethane can be introduced at the bottom of the melt by means of a perforated, inverted iron cup. Vaporization of these fluxes makes them act in a manner similar to the gaseous fluxes. Care must be taken to make sure these fluxes are completely dry before they are introduced into the melt. Since these chemicals are hygroscopic and tend to absorb moisture from the air, they may actually add hydrogen to the melt instead of eliminating it. Adequate venting and hooding must be used to carry off the chloride gases as they leave the surface.

This type of fluxing is best accomplished at about 1350°F, the temperature recommended for gaseous chlorine fluxing. About one pound of this type of flux should be used for every thousand pounds of melt.

Grain Refining: To offset coarsening of the grain brought about by excessive fluxing, and to produce a finer grain in the solid casting, boron, chromium, and titanium are added to the molten alloy. To produce the best results, these grain refiners are usually put in the molten metal immediately prior to pouring. Titanium, in amounts up to 0.2 percent, is the element preferred for grain refinement, being added in the form of a 5 percent alloy hardener or a potassium titanium fluoride salt. In either case, the total amount of titanium must be rigidly controlled.

Chromium is usually employed in the form of an aluminum chromium hardener. Boron is added as solid or gaseous flux, or as an aluminum-boron, aluminum-boron-titanium, or potassium fluoborate salt.

Temperature: Good foundry techniques call for the careful control of the temperature of the alloy both in the melting furnace and as it is poured into the mold. Experience has proven that only by such close control can consistently good castings be obtained. Too high a temperature in the furnace will result in excessive gas absorption and oxide formation and will give porous, grainy castings. Pouring at too low a temperature will allow solidification of the metal before all voids in the mold are filled and will also produce cold shuts.

Molten aluminum alloys must be protected from three common sources of trouble: (1) The tendency of molten aluminum to absorb and dissolve gases, especially hydrogen; (2) Oxidation and resultant dross formation; and (3) Contamination.

Any hydrogen that is dissolved in the molten aluminum is liberated when the aluminum alloy solidifies, causing porosity in the casting. Hydrogen is encountered in the foundry in the following hydrogen compounds which react with the molten aluminum to liberate pure hydrogen which is instantly absorbed: (1) Atmospheric moisture. This source is more severe the higher the humidity of the air; (2) Moisture and hydrocarbons formed as combustion products of the fuel. This is a problem in direct-fired furnaces where the combustion products impinge on the melt; (3) Hydrogen retained in the ingot; (4) Moisture or oil on the surface of the aluminum ingot. This gas source is more severe the more corroded the surface and the fewer precautions taken (such as preheating) before the ingot is put in the melt; and (5) Moisture or other hydrogen forming constituents in the mold material.

Low permeability and high moisture content in green sand molds will cause gas absorption while the metal is being poured into the mold cavity.

The gas absorption will be higher the higher the temperature of the molten aluminum, the longer it is held in a molten condition, and the more direct the contact between the molten metal and the hydrogen-forming gases. Considerable resistance to gas absorption is offered by the oxide envelope which surrounds the molten aluminum.

Gas absorption is at a minimum when the melt stands quietly and the oxide skin on the top of the melt remains unbroken. If the oxide skin is broken and the molten aluminum comes in contact with hydrogen-forming materials, or if hydrogen-forming materials are introduced below the surface, then gas absorption is very rapid. Good melting technique calls for minimum exposure of the surface of the melt to the atmosphere. This means a minimum of stirring. The metal must be poured quickly in a short wide stream.

On molten aluminum alloys, the oxide film prevents the formation of more oxide, and stops gas absorption. However, the dross that forms as a result of oxidation may be trapped in the metal and cause a defect in the casting. This dross may occur in the casting because of excessive agitation of the aluminum in the melting pot, poor transfer of the molten metal from the pot to the pouring ladle, poor pouring techniques, or from undue agitation of the alloy as it flows through the mold cavity. Dross is a serious problem with aluminum alloys because the low density of aluminum does not force the oxide dross to the surface.

Oxides are also introduced when scrap is thrown directly into the melt. It is best to melt scrap and pour it into ingots before introducing it into the foundry melt. In this way the scrap can be fluxed and cleaned to eliminate both oxides and hydrogen-forming materials.

The following procedures, if properly applied, will satisfactorily control oxide formation and hydrogen absorption: (1) Keep the temperature of the melt as low as possible. This temperature should be the minimum pouring temperature that will produce consistently sound castings; (2) Hold the aluminum alloy in the molten condition no longer than necessary; (3) Keep the humidity low in the furnace and in the pouring room; (4) Limit contact of the melt with combustion gases; (5) Agitate the molten alloy as little as possible. If it must be stirred, be careful to disturb the surface no more than necessary. When using gaseous fluxes, feed gas so it produces a gentle rolling of the surface, not a turbulent bubbling; (6) Skim only once, just before pouring, except as modified by fluxing requirements; and (7) Avoid introducing hydrogen-forming materials below the surface of the melt.

All equipment used to handle molten aluminum must be kept thoroughly clean to minimize contamination by dirt or iron pickup. All loose scale and oxides should be scraped from pots and ladles. All iron equipment should be inspected periodically to make sure that a sufficient coating of protective material is present on all surfaces coming in contact with molten alloy. A suitable coating can be made by mixing four pounds of whiting, one-half pint of sodium silicate, and one gallon of water.

TABLE 3 — COMPARISON OF WEIGHT OF ALUMINUM WITH EQUAL VOLUMES OF OTHER METALS

METAL	RELATIVE WEIGHT FACTOR
Magnesium	.64
Aluminum	1.00
Titanium	1.68
Cast Iron	2.63
Zinc	2.64
Tin	2.70
Cast Steel	2.90
Cast Brass (35% Zinc)	3.14
Monel Metal	3.25
Cast Bronze (5% Tin)	3.28
Copper	3.32
Lead	4.20
Uranium	6.93

NOTE: Weight of a given volume of aluminum is taken as 1.00 or "the unit" here. To find the weight of any other metal part of equal volume (size), multiply the weight of the part in aluminum by the "relative weight" factor shown in right hand column.

TABLE 4 — ANNEALING AND STRESS RELIEVING ALUMINUM CASTINGS

TREATMENT	APPLICATION	PURPOSE	TEMP.—°F	TIME—HRS	TYPE OF QUENCH
Annealing	Sand and P.M. Castings	To stress relieve & reduce growth	650	2	Air cooled
Stress Relieving	Die Castings	To reduce internal stresses	350-500	4-6	Cooled in still air
Annealing	Die Castings	To increase ductility	500-700	4-6	Furnace cooled or cooled in still air

The coating is applied by first heating the surface to be coated to about 300°F and then brushing or spraying. A continuous film of moderate thickness should be built up on the surface. Too heavy a film tends to spall or flake off. Be sure to apply the coating to all surfaces that will come in contact with the molten metal. After the units are properly coated, they should be thoroughly heated before being used to make sure that all moisture has been driven off.

The chemical composition of an aluminum alloy must be controlled within narrow limits to achieve certain desired characteristics. Changing this chemical composition by careless handling of the molten metal or by initial contamination with undesired elements negates the alloying work of the prime producer.

In foundries that work with a variety of metals, or even with a variety of aluminum alloys, it is comparatively easy to contaminate an aluminum alloy. For this reason, equipment must be cleaned thoroughly when it is charged with a new alloy composition, and all scrap and charging materials must be well segregated. Establishment of a segregated scrap storage system will assure the production of clean foundry alloys with uniform characteristics. It thus is important to classify and segregate all aluminum scrap, and to use special care in identifying scrap charged into melting furnaces.

TRIMMING AND CLEANING

The light weight of aluminum alloy castings and their favorable machining characteristics make them easy to handle and easy to trim. In addition, a variety of tools can be used for cleaning the surfaces of castings. Surface discolorations or rough spots can also be removed easily.

Band saws are suitable for removing most gates and risers . . . either a heavy duty woodworking type for average weight castings, or a high speed metalworking saw for heavy castings. Circular saws and hack saws give closer and straighter cuts in some applications. Semi-high-speed or high-speed-steel blades are suitable, although cemented-carbide-tipped teeth may be used at speeds up to 7500 feet per minute.

Cleaning: A variety of methods, including liquid rinses, grinding, filing, and surface blasting are used to clean aluminum castings.

A commonly used method of cleaning aluminum castings is by the use of compressed air blasting with sand, dust, shot, or steel grit. This process has the advantage of revealing unsound areas that lie immediately below the surface, enabling it to be used profitably for the inspection of some castings. Various surface imperfections such as discoloration and minor roughness due to casting or grinding can easily be masked or removed.

TABLE 5 — PATTERNMAKER'S SHRINKAGE FOR SAND CASTINGS OF VARIOUS METALS

MATERIAL	SHRINKAGE In./Ft
Aluminum Alloys Aluminum silicon alloys and the larger castings have less shrinkage than other alloys and smaller castings.	1/10 – 5/32
Magnesium alloys	5/32
Brass & Bronze	3/16
Gray Iron	1/10
Steel	1/4
Malleable Iron	1/8

TABLE 6 — COMPARISON OF ALUMINUM ALLOY CASTING METHODS

CASTING METHOD	COST		PRODUCTION QUANTITIES	MECHANICAL PROPERTIES	SURFACE FINISH	LIMITATIONS		DIMENSIONAL ACCURACY	MINIMUM SECTION THICKNESS inch
	PRODUCTION EQUIPMENT	UNIT CASTING				CASTING SIZE	ALLOY		
Green Sand	Low	High	Medium	Medium	Fair	None	None	Fair	1/8
Baked Sand	Medium	High	Medium	Medium	Fair	None	None	Fair	1/8
Semi-Permanent Mold	High	Low	Medium Large	High	Fair to Good	To Medium	Medium to High Fluidity	Good	1/16
Permanent Mold	High	Low	Medium Large	High	Good	To Medium	Medium to High Fluidity	Very Good	1/16
Die Casting	Very High	Lowest	Very Large	High	Very Good	To Medium	High Fluidity	Excellent	1/32
Centrifugal	High	Low	Medium	Medium High	Good	Limited by Shape	None	Good	1/8
Investment	Medium	High	Small	Medium	Excellent	Small	High Fluidity	Excellent	1/8 - 1/32
Plaster	Medium	High	Small	Low	Excellent	Small	High Fluidity	Excellent	1/8 - 1/32

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TABLE 7 — RECOMMENDED CUTS, SPEEDS, AND FEEDS FOR MACHINING ALUMINUM CASTING ALLOYS

OPERATION †	ROUGH MACHINING			FINISH MACHINING		
	Maximum Cut Inches	Speed Feet per Minute	Feed, Inches	Cut, Inches	SPEED Feet per Minute	Feed, Inches
LATHE TURNING						
Class A alloys, not heat treated	0.25 (a)	500 to 900	0.020 to 0.030	0.002 to 0.010	Maximum	0.002 to 0.010
All Others	0.19 (a)	400 to 800	0.007 to 0.020	0.002 to 0.010	600 to 900	0.002 to 0.010
MILLING						
Class A alloys, not heat treated	0.25	400 to 600 (b) 500 to 700 (c) Maximum (d)	5 to 15 (e)	0.010 to 0.020	500 to 700 (b) 500 to 700 (c) Maximum (d)	10 to 25 (e)
Class A alloys, heat-treated **Class B alloys**	0.25	400 to 600 (b) 500 to 700 (c) Maximum (d)	40 to 10 (e)	0.010 to 0.020	500 to 700 (b) 500 to 700 (c) Maximum (d)	5 to 15 (e)
Class C alloys	0.25	300 to 500 (b)	3 to 8 (e)	0.010 to 0.020	500 to 700 (b)	4 to 10 (e)
BORING						
Light duty (1 to 2 inch)	0.09 (a)	Maximum (f)	0.010 to 0.020	0.010 to 0.020(a)	Maximum (f)	0.001 to 0.005
Medium to heavy duty	0.25 (a)	600 to 1000	0.007 to 0.015	0.010 to 0.020(a)	600 to 1000	0.001 to 0.003
SHAPING						
Heavy duty (36 inch)	0.25	Maximum (g)	0.010 to 0.030	0.005 to 0.010	Maximum (g)	0.100 to 0.150
PLANING	0.38	Maximum (h)	0.025 to 0.100	0.005 to 0.015	Maximum (h)	0.050 to 0.375

† Class A alloys are 122, A214, B214, D612, 613, Almag 35.
† Class B alloys are 108, 142, 195, 214, 319, 355, C355.
† Class C alloys are 13, 43, A132, 356, A356, 357, A357, TENS 50.
(a) Cut measured on radius.
(b) For carbon steel tools.
(c) For high-speed steel tools.
(d) For cemented carbide tools.
(e) Travel of work.
(f) Peripheral speed of tool is maximum of most machines.
(g) Travel of ram.
(h) Speed of table.

REYNOLDS

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